Measuring change in fish communities: from monitoring to metrics to management

Report of a workshop and recommendations for research

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Abstract

Ecological monitoring programs are often designed to provide information on the status and/or trends of populations, communities, and ecosystems that are of interest to natural resource managers. The information these programs provide is then used by managers to make management decisions (i.e. increase or decrease extraction levels, allow or restrict access), and at the same time can be used to evaluate the effectiveness of such actions. To be most useful, monitoring programs need clear and meaningful response metrics, which can be complex for ecosystem or community monitoring programs. In recent years, a number of peer-reviewed studies have used biomass as the primary response metric for reef fish community monitoring programs, and this metric is currently being considered as a response or performance measure for National Coral Reef Monitoring Program of NOAA's Coral Reef Conservation Program. However, to date there has been no critical evaluation of the utility of biomass-based metrics or comparison with possible alternative or complementary metrics to describe the status of these complex communities. To address this need, we have initiated a project to evaluate the utility of biomass-based metrics and their relationship to other population and community response variables and determine the relative strengths and weaknesses of different metrics for different questions and situations. For this preliminary report, we outline the results of a workshop that included NOAA and academic scientists. The goals were (1) to clearly frame the difficulties of creating appropriate response metrics for complex monitoring programs, (2) identify a range of potential metrics, (3) develop a conceptual analytical framework to evaluate candidate metrics, and (4) outline a workplan for a future project designed to address this research question. In addition, we allocated resources before and after the workshop to assemble datasets from three major NOAA coral reef fish monitoring programs. We found that biomass is only one of many potential responses that may have utility for understanding changes in fish communities, and that the outcomes are likely to be highly context dependent. Other potentially useful responses include abundance and biomass of key subsets of the community, as well as more derived metrics such as size spectra. We also include the major management uses for monitoring programs, the specific information they require, as well as a list of the important attributes for all potential metrics, their links to management, and the key challenges to using each metric. We outline the required next steps to determine which metric, or likely collection of metrics, will be most useful in describing the status and changes of reef fish communities worldwide.

Introduction

Response metrics are critical parts of any monitoring program. These measures allow scientists and managers to evaluate the status of their systems of interest and better understand and predict the impacts of management, other anthropogenic factors, and natural events. In their simplest forms, these response metrics provide information about the status and trends of an ecosystem; that is, is the status good or bad, and is the situation improving or declining. Ideally, monitoring programs report a limited number of highly informative metrics to simplify data collection and interpretation, and to facilitate communication of these results to third parties (e.g. policy makers, stakeholders, the public, etc). In coral reef systems, scientists have employed a wide variety of monitoring programs and approaches, and despite the urgent need for clearer scientific information on these heavily impacted marine systems, there has been little consensus in the literature about how best to design a monitoring program, how best to report program results, and how best to link results to management need (Nicholson and Jennings 2004, Jennings et al 2005, Fulton et al 2005, McClanahan et al 2012). Despite this lack of consensus, many recent peer-reviewed publications have reported total fish biomass as a community response metric, making the often implicit assumption that higher levels of fish biomass correspond to a 'better' state (e.g. Sandin et al 2008, McClananhan et al 2012, Aburto-Oropeza et al 2011). Within NOAA's Coral Reef Conservation Program (CRCP), the National Coral Reef Monitoring Program (NCMRP) working group and the CRCP Performance Measures have considered using biomass as a response metric to describe the status and trends of fish communities. However, as with any single metric, 'fish biomass' condenses a considerable amount of information into one number, thus potentially losing a great deal of information in the process. In addition, we know very little about the factors that influence natural levels of variation in fish biomass, such as productivity, island and/or reef size, latitude, and other factors (but see Blanchard et al 2008, Nadon et al 2012, Richards et al 2012).

Therefore, we are still uncertain whether biomass is the most appropriate response metric, and we need to know under what circumstances this and other response measures perform best, and under what circumstances they perform less well. Such information is critical since it will allow NCRMP, CRCP, and the broader reef fish ecology and reef fish management communities to use the best possible metrics to describe the status and trends of fish communities. As CRCP moves forward with program-wide performance measures, additional work is needed to ensure that CRCP's chosen performance measures are the most appropriate indicators of project and program success, as well as meaningful indicators of ecological change. Finally, biomass is being used more and more as a metric in the peer-reviewed literature and by the management community (e.g. McClanahan et al 2007, Sandin et al 2008, Mora et al 2011, Aburto-Oropeza et al 2011), and it is critical to better understand the value and limitations of any response metric before using it as a basis for management actions.

This report details the results of a planning workshop convened with NOAA and academic scientists. This workshop sought to examine the challenge of identifying, evaluating, and using appropriate response metrics that consistently and objectively describe the 'state' of coral reef fish assemblages at a variety of spatial and temporal scales using data from monitoring programs In addition, it identified a variety of potential metrics, including a range of their attributes, benefits, and limitations, developed a conceptual analytical framework to evaluate candidate metrics, and outlined a workplan for a future project designed to address this problem.

Major conceptual issues to consider

Fish community response metrics, like all metrics generated from monitoring programs, will be bounded in large part by the data the monitoring program collects. In an ideal situation, we would choose an optimal metric and design a monitoring program to collect that information. In practice, monitoring programs are often limited to a small suite of data by logistics and funding constraints. Fortunately, the vast majority of reef fish monitoring programs generally collect useful information in a similar way: nearly all collect information on individual species abundance and size within a sample of fixed and known area (Menza et al 2006, Brandt et al 2009, Brainard et al 2012). Therefore, response measures will be limited to information that can be derived from these data. For example, sex ratio is often cited as an indicator of environmental or anthropogenic pressures, but since few species can be sexed during visual surveys (and sex/stage data are often not collected for those species that can be sexed visually), such a metric cannot be computed from these data. Using such a metric, therefore, may require modifying data collection protocols. For the bulk of the NOAA (and many academic) monitoring programs, potential metrics are limited to: species, including higher level information such as trophic group, fishery group, or taxonomic family; presence/absence at the species level or higher; abundance/density at the species level or higher; size structure, at the abundance level or higher; and any metric that combines one or more of these, such as biomass (size x abundance).

It is also important to consider how a metric will be used. The ultimate uses of a metric or suite of metrics should be closely related to the goals of the monitoring program, such as whether the program seeks to inform fisheries management, biodiversity conservation, or some other purpose (Table 1). In practice, however, these links may not be explicit, which will likely lead to confusion in interpretation of the results of monitoring data. In addition to clearly identifying the uses for response metrics, metrics need to have sufficient precision to be usable for identifying targets and/or thresholds. Targets/thresholds should be identified *a priori*, and should be linked to some sort of potential management action. Without known levels of precision, clear targets, and clear actions, monitoring programs will be far less useful than they could be.

We must also consider the effect of scale. Adequate response metrics in monitoring programs should be useful over multiple spatial and temporal scales, as well as differing scales of human impacts. However, it is likely that different metrics may perform better in different places, over different levels of impacts, and over different scales. Temporal scales often include three separate components: 1. Status, or what is the current status of a system; 2. Trend, or how is the system changing; and 3. Resilience, or how well does a system respond after a disturbance and how long does it take to recover. Spatial scales and anthropogenic influences are often tightly linked, but within coral reef systems, scales of human impact may overwhelm variation in space alone. For example, there may be island-scale variation in fish assemblages across the Main Hawaiian Islands, but the high human population density and heavy fishing pressure throughout the archipelago may make these differences difficult to detect. We must also consider the effects of a variety of potential driving factors, such as Pacific vs. Atlantic reefs, high latitude/high productivity vs. low latitude/low productivity, continental vs. island, and pristine vs. high human impact.

One of the greatest challenges in determining what metric to use is how best to measure the performance of a metric, particularly for multi-species or ecosystem monitoring programs like those in NCRMP. For single species, performance measures are often straightforward, such as total abundance or fishable biomass. However, understanding empirical ‘state’ of a community or ecosystem is far more complicated, and this problem can be somewhat circular: we seek a metric to help us evaluate the state of a system, and at the same time we need a way to determine how well that metric describes the state of the same system. The inherent circularity of this issue will make it one of the most difficult issues to address, but it is not intractable. First, we will generate a variety of different metrics and examine correlations among them. High performing metrics should correlate well with other generally plausible metrics. In addition, for locations or combinations of time and place that we believe we can reasonably characterize along some scale of condition (e.g. near pristine, poor/heavily-impacted), we can evaluate the extent to which different metrics describe the state of those systems. Finally, we can identify clearly weak or unsuitable metrics, which do not correlate with clear gradients in condition or impact.

Evaluating resilience will also be a challenge. Resilience has emerged as an especially desirable property of reef ecosystems but how to measure it and what management actions may promote it remain challenging, in part because it is difficult to define operationally. However, some of the long time series within NOAA coral reef monitoring data may provide an opportunity to examine resilience explicitly. It will require a data-rich system, such as a long time series and/or large spatial extent, and clear perturbations in space and/or time. However, it is still unclear if examine resilience is feasible.

Initial results

The planning workshop began by outlining some of the major conceptual issues. First, we discussed the broad management categories for which monitoring data are collected (Table 1). Data and response metrics from monitoring programs should be explicitly responsive to the these management needs. To evaluate potential response metrics, we must first generate a list of all potential metrics that may describe the state of a reef fish community. We listed a wide range of potential metrics, some of which will be relatively simple to calculate, and some of which will be more complicated (Table 2). We also included a series of attributes of each metric that would influence its ultimate utility, such as feasibility of data collection for that metric, relationship to broad management needs, ease of setting management targets, and potential limitations. A list of these metrics, their potential utility, as well as metrics of subsets of the community, follows; table 2 expands on this list and includes a variety of other attributes of each metric.

1. Biomass, which should provide some information about the status of a community, since it integrates both size and abundance information.
    a. Total fish biomass
    b. Biomass, excluding highly variable species (e.g. sharks)
    c. Biomass by trophic group
    d. Biomass of fishery target species

    e. Biomass of species of concern
2. Instantaneous potential productivity/community productivity. This measure may be a better measure of the true fishery yield of a system, and may also be related to resilience, since communities with high productivity should respond faster to disturbance. This metric requires a great deal of additional information, such as growth rate and other life history data, for every species in the assemblage.
3. Multispecies spawning potential ratio (SPR). SPR is a standard fishery metric, but also requires a growth rate and other life history information for each species.
4. Abundance. This may be a difficult metric to interpret since ecological theory on coral reefs does not provide clear predictions about how disturbance may influence total numbers of fish in a multispecies assemblage.
    a. Total abundance (i.e., total numbers of all fish)
    b. Abundance excluding highly variable species. Subset of highly variable species may be different than that of biomass
    c. Abundance by trophic group
    d. Abundance of fishery target species
    e. Abundance of species of concern
    f. Abundance of reproductive individuals
    g. Abundance of exploitable phase individuals
5. Size spectra, with abundance and biomass by size. Slopes of the size spectra will provide information about the degree to which an assemblage is dominated by large or small individuals.
    a. All species
    b. By functional group
    c. By reproductive or exploitable phase individuals
6. Trophic measures. Ecological theory predicts that low productivity and/or heavily disturbed systems should have a lower trophic level.
    a. Mean trophic level
    b. Predator/prey ratios (by biomass and/or abundance)
7. Diversity/Richness. Ecological theory makes a variety of predictions about the impacts of disturbance and productivity on diversity and richness.
    a. Total diversity/richness
    b. Diversity/richness within functional groups
8. Age distribution. Slopes of the age spectra will provide information on the degree to which an assemblage is dominated by young or old individuals, but this will require data on size-at-age for every species in the assemblage.
    a. All species, which should be analogous to size spectra
    b. Within functional/target groups
9. Multivariate methods. There are a variety of multivariate methods that have been used to discriminate communities. It is difficult to apply these methods across assemblages of differing species pools but they can be used for temporal comparisons or comparisons among subregions within different region.

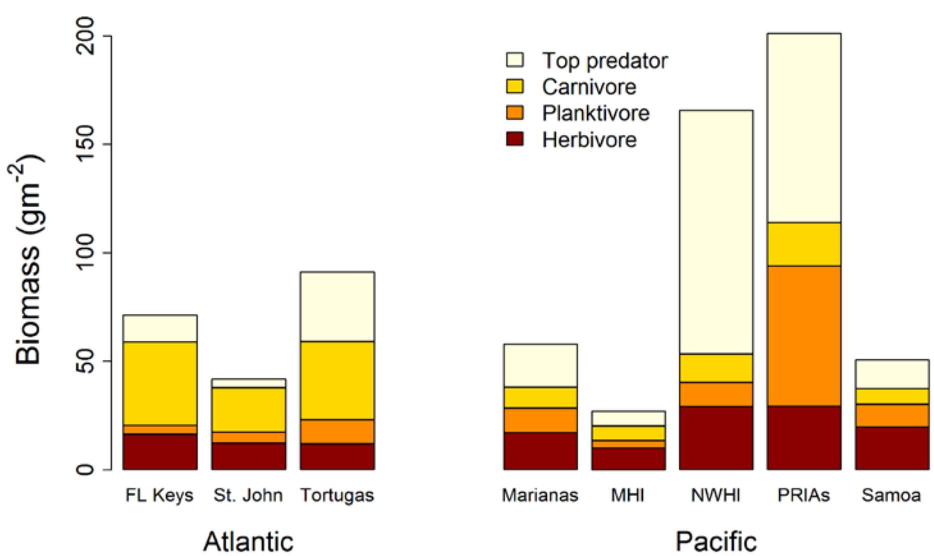
To evaluate the candidate metrics, we propose to examine a variety of attributes of each metric. These could include: the spatial and temporal variability, repeatability, the correlation and sensitivity to known disturbance and management actions, the variability among different data collection methods, the signal across a wide range of conditions, the correlation with other metrics and other physical factors, practicality and interpretability, and the previous applicability and prior successes.

We will also include several NOAA and non-NOAA monitoring datasets, many of which include broad spatial and/or temporal coverage. Initially, we propose to focus on datasets collected or managed by co-authors. These include: NCCOS monitoring data from the USVI, parts of Puerto Rico, and the Flower Garden Banks, spanning the last 10, 10 and 7 years, respectively; RVC data from the Florida Keys and the Dry Tortugas, spanning 32 and 15 years, respectively; CRED data from 40 islands in 7 regions from U.S. Pacific states and territories, spanning 5-10 years; Scripps Line Islands data from all 11 Line Islands and 5 Phoenix Islands, spanning 7 years, with most islands visited 3 times during that period.

Using these data, we have conducted some initial analyses, focusing on differences in biomass by trophic group and across regions within ocean basins. For all of these analyses, we used published length-weight relationships to convert abundance-at-size data from each monitoring program to biomass for each species. Species were assigned to a trophic group: herbivores include those species that feed primarily or exclusively on benthic algae or detritus; planktivores include those species that feed primarily or exclusively on plankton; carnivores are generally smaller predators that either feed on small fishes or benthic invertebrates; and top predators are larger predatory fish that feed primarily or exclusively on larger fish as prey. We chose to include only those datasets that surveyed randomly selected sites around an and entire island/archipelago or region, which in turn allow us to scale up mean site estimates to generate estimates of biomass per trophic group for an entire island/archipelago/region. In the Atlantic, this included SEFSC data from the Florida Keys and Dry Tortugas, and NCCOS data from St. John; for the Pacific, this included CRED data from all of the major island groups. To summarize all data across both basins, we plotted mean fish biomass per unit area, per trophic group for each region or archipelago, using the region- or archipelago-wide estimates of biomass. As a correlate in the Pacific, we used existing estimates of human population density per island, and plotted human population density vs. biomass per trophic group for each island, separating out each archipelago. Finally, we examined size spectra for the three Atlantic regions. To generate size spectra, we estimated the total biomass (across all trophic groups) present in each 10-cm size class, again using the region-wide estimates of biomass in each size class. Size spectra slopes were generated using a linear regression of the log of biomass and the midpoint of each size class.

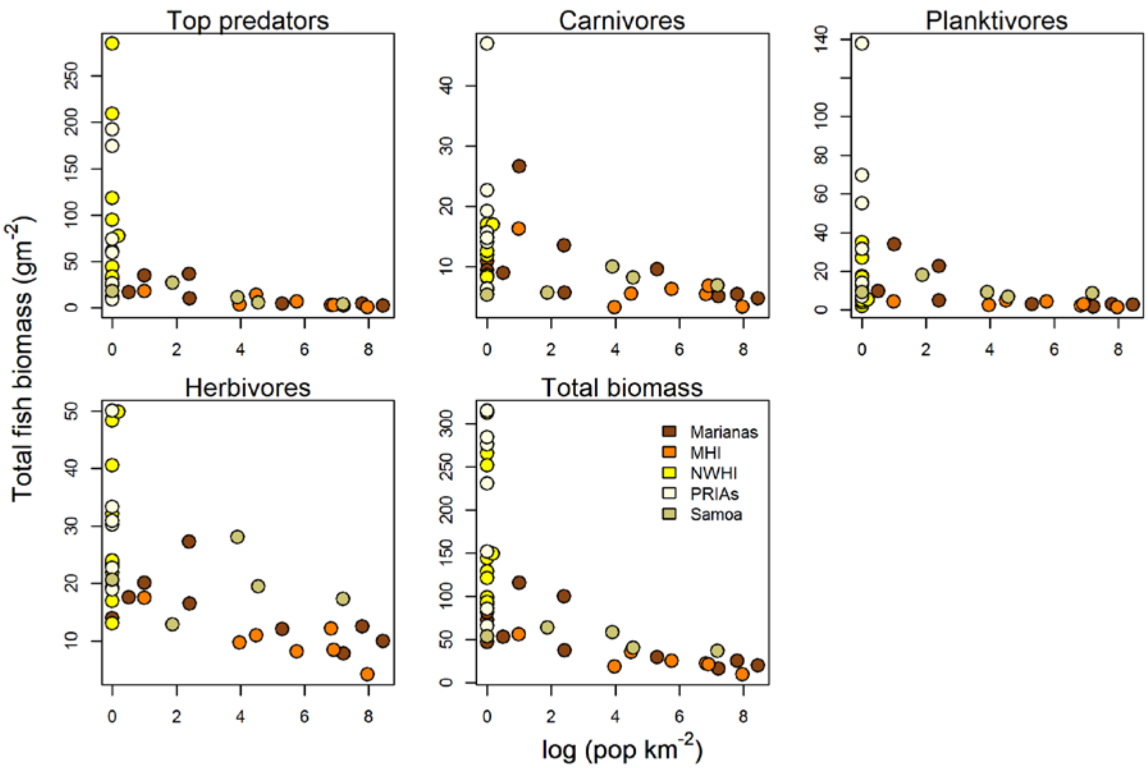
These analyses of existing NOAA monitoring data reveal a number of patterns. Total fish biomass varies by twofold within three regions of the Atlantic, and 8-10 fold across regions in the Pacific. However, patterns by trophic group are highly variable between the Atlantic and Pacific, as well as within the Pacific, suggesting that different mechanisms may control these patterns in different oceans/regions (Fig. 1). In addition, while some of the Pacific regions appear to have far more top predator biomass, all three regions in the Atlantic appear to have relatively high levels of carnivore biomass. This intriguing trend is worthy of more detailed exploration in follow up research. In addition, it is important to note that some of the observed differences may be the result of different methodologies (e.g. transect in St. John, point count in Florida and the Pacific). We anticipate that some response metrics may be robust to different methodologies, allowing us to make comparisons across studies that use different methods. However some response metrics may be extremely sensitive to methodology, precluding comparisons across some studies. We have included a column with our initial expectation of how important method may be to each response metric in Table 2.

Figure 1. Total fish biomass across all NOAA monitored areas by trophic group



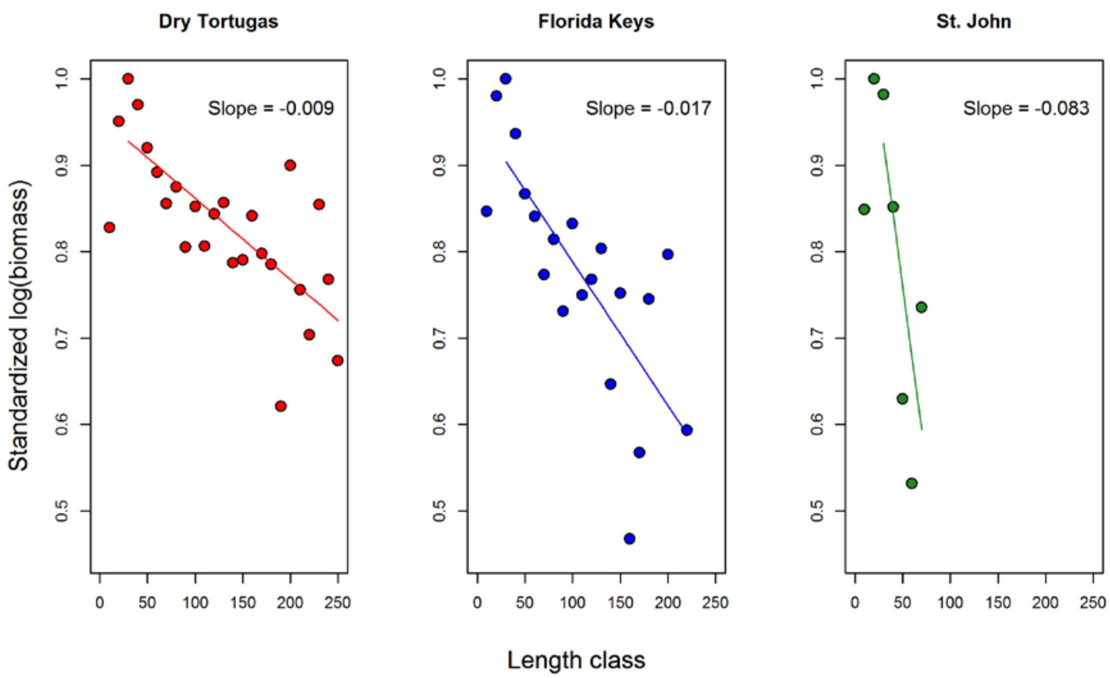
Across the Pacific, we also have information on human population density, allowing us to relate biomass by trophic group to human population across a range of archipelagoes. Among the Pacific RAMP data, increasing human population density is generally correlated with lower biomass across a range of trophic groups (Fig. 2). In most cases, there is a sharp change in maximum biomass and variability from no human population to any low value of human population. However, the lowest values across all groups and all archipelagoes are generally found around islands with the highest human population density. We will obtain this human population data in the Caribbean for future analyses.

Figure 2. Fish biomass by trophic group in different Pacific island groups by human population size



In addition, we also examined slopes of size spectra across a subset of locations. Size spectra examine the rate of change of the relationship between size-class specific biomass and the size class itself. A more negative slope indicates that the assemblage is more dominated by smaller bodied individuals, while a less negative slope indicates that the assemblage has relatively more biomass in the larger size classes. A zero slope indicates that all size classes contribute equally to the total biomass, and the rare case of a positive slope indicates that the assemblage is dominated by larger bodied individuals. Within the Atlantic, the size spectra slope in St. John is the most negative, suggesting that this system has very little biomass in larger size classes. Inspection of the data reveal that virtually none of the biomass is found in size classes above 60cm.

Figure 3. Size spectra plots for three locations in the Atlantic. 'Standardized' biomass is the log(biomass) in each size class divided by the maximum log (biomass) in any size class in a given location. This standardization allows for comparison among slopes, or the relative distribution of biomass in different size classes, in locations that have been sampled with differed methods and that may have different total biomass.



Future steps

To thoroughly investigate the utility of biomass and a range of other reef fish community response metrics will require a dedicated project. The remainder of this report is dedicated to describing the scope and resources needed to conduct this project as determined by workshop participants. We expect that a postdoctoral fellow with training in reef fish ecology, dataset management, and data analysis will be able to accomplish this project over two years. The co-authors of this report could serve as project co-mentors. We would expect that this project will greatly enhance our understanding of reef fish communities and provide clear guidance on what different metrics tell us and under what circumstances they are most informative. We anticipate that this information will be extremely useful to CRCP, federal, state, and local users of NOAA monitoring data, as well as reef managers throughout the world.

To achieve these results, we anticipate that this project will take several steps. First, the project leader (likely the postdoctoral fellow) will compile the available datasets. This will include NOAA datasets used in this report, as well as data on a variety of potential covariates wherever possible, including strata/habitat, physical characteristics such as productivity, island size, and isolation, information on human impacts, benthic data, as well as others factors. We have already begun the process of assimilating and organizing the disparate NOAA datasets for this report. We anticipate that completing this process should require no more than a month or two during the outset of the follow up project. Obtaining and organizing data on covariate datasets will be more complicated, and will likely require several additional months, depending on the state and availability of these datasets. Some covariate datasets will be relatively simple to assimilate (e.g. benthic monitoring data collected by NOAA programs, benthic habitat maps, etc.), while others may be difficult to obtain (e.g. data on human impacts).

We will then define gradients along which we expect metrics to vary, such as human population (e.g. Fig. 2), productivity, island size, and others. We must then define the list of candidate metrics. An initial list, including a variety of attributes of each metric, is provided in Table 2. However, there may be other metrics we have not yet considered. Each metric will need to be operationalized, with explicit computations for each. Once metrics are defined, we will generate descriptive statistics for each metric in each location. The resulting distributions will be plotted to explore the overall shape and examine outliers, both of which may be informative. We will explore the relationships between metrics and covariates as well as among metrics. We will also attempt to partition the variation among factors in an effort to determine the relative importance of other factors such as location, proximity to human populations, etc. We anticipate that completion of this project will require a two-year postdoctoral fellowship and a total budget of between $150,000 and $200,000.

With any large-scale analytical project, there are a number of significant challenges to overcome. We expect that different metrics will be responsive to different covariates, and that some of these responses may be context dependent. For example, because there are many differences between the Atlantic and Pacific basins, reef fish communities in these different oceans may respond very differently to similar covariates, such as human population (e.g. Nadon et al 2012). However, for a metric to be most useful, we must at the very least understand how it varies with different covariates, as well as with different contexts.

Ultimately, these analyses may show that we cannot use a single metric to define the status of all reef fish communities in all locations at all times. In that case, this project will provide clear guidance about what metrics are most appropriate in what situations and locations, and for what purposes. Armed with this information, the end users of monitoring data products will be much better prepared to make appropriate decisions based on these types of data.

Table 1. Potential management uses for monitoring data and metrics, information needed, and challenges

Management category	Actionable Metrics	Key Challenges
Fishery Management	abundance/size/SPR/age/biomass of key species	identifying key harvested species; unknown life history parameters; some depth/habitats not sampled; spatial coverage
Area Management	CONSERVATION: abundance/size/biomass of key species; diversity FISHERIES: SPR/age/larval export; spillover	need for adequate replication within (frequently) small areas; unknown fish-movement component
Habitat Quality/Watershed Management	biomass and diversity; abundance and size	complex ecological/fish-habitat relationships; fish-centric program misses majority of meaningful responses; difficult to attribute cause and effect
Species of concern	abundance/occurrence/size structure; likely large effect size only; potentially stronger interest in trends through time or in identifying hotspots	infrequently encountered; requires large sample size or area
Resilience	diversity within functional groups; adequate herbivory (e.g. grazing rates); age structure	unknown connectivity; patchy distributions complicate management and interpretation of monitoring data

Table 2. Candidate metrics and their attributes

Metric	Feasibility/ challenges	Indicator Use/Value (what is it signal of)	Habitat Dependence	Useful for Fishery Mgmt	Useful for Spatial Mgmt	Useful for Habitat Quality Mgmt	Evaluate Resilience	Methodological dependence	Actionable by managers? Can we set targets?	Limitation/Needs
Biomass										
Biomass (all)	Expectation is temporally and spatially variable	All else equal, impacts will reduce biomass; sensitive to fishing pressure/human impacts; integrates abundance and size	Yes, and testable	Yes; Target relative to B zero and MSY/SPR	Yes; target relative to B0 (conservation context)	No as static measurement; but can focus on change over time as habitat quality increases/ decreases	Maybe; can be tested vs actual resilience	Different methods may generate different values (but this is testable with data in hand)	Yes, with reasonable expectations	Expectation is temporally and spatially variable
-Biomass (subset, excl highly variable)	Reduced variability from total biomass, but loss of signal from variable taxa	All else equal, impacts will reduce biomass; sensitive to fishing pressure/human impacts; integrates abundance and size	Yes, and testable	Yes, if include fishery species	Yes	No as static measurement	Maybe; can be tested vs actual resilience	""	Yes	Reduced variability from total biomass, but loss of signal from variable taxa
-Biomass trophic/ functional	clarity and justification for functional grouping	Ecosystem functioning	Yes, and testable	No	Yes, case dependent	Maybe	No	""	Yes	clarity and justification for functional grouping
- Biomass fishery target species	classify target species	Standing stock status	Yes, and testable	Yes, if include fishery species	Yes	Maybe	No	""	Yes	classify target species
-Biomass species of concern	Identify species of concern; species of concern often rare/mobile/ infrequntly encountered	Species of concern	Yes, and testable	No	Yes	Maybe, if habitat is important to species of concern	No	""	Yes	Identify species of concern

Instant. potential productivity (~dB/dt)	Yes, but requires life history parameters (age and growth) and spatial/temporal variance in VBGF parameters	Rate of somatic growth of the assemblage	Probably, but unknown for most species	Yes	No	No	No	Unknown	Yes, but need VBGF	Need VBGF for all species and spatial/temporal variance
-SPR (or equivalent)	Yes for data rich taxa, but still need B0 and size at maturity	Maintain reproductive potential	Yes	Yes	Yes	No	Maybe	Unknown	Yes	Need B0, size at maturity
Abundance										
Total abundance	Yes	Unclear	Yes, and testable	No	No	No	No	Yes	Yes	Few/none
-Abundance (subset, excl highly variable)	Yes	Unclear	Yes, and testable	No	No	No	No	Yes	Yes	Few/none
-Abundance trophic/ functional	Yes	Unclear	Yes, and testable	No	No	No	No	Yes	Yes	Few/none
-Abundance fishery target species	Yes	Stock status?	Yes, and testable	Yes	Yes	Maybe	Yes	Yes	Yes	Few/none
-Abundance species of concern	Yes	Status of species of concern	Yes, and testable	No	Yes	No	No	Yes	Yes	Few/none
Size spectra (abundance or biomass), all fishes	Yes, but need to assume size frequency distributions are at equilibrium	Simplified size distribution	Yes, and testable	Yes	Yes	Maybe	Yes, but interpretation may be difficult	Some	Yes	Assume size freq dist at equil
- within functional group(s)	Yes, but need to define groups	Simplified size distribution	Yes, and testable	Yes	Yes	Maybe	Yes, but interpretation may be difficult	Some	Yes, but need to account for zeros	Define groups; statistical improvement

Trophic										
- mean trophic level	Yes, but perhaps not precise, and trophic level of a species may change in space and time	Fishing pressure (or human impact)	Yes, but habitat may confound analysis	No	No	No	No	Likely low	Maybe	assignment of trophic level may vary w species/ location/time
-predator/ prey ratio (by biomass)	Yes, but need to define predator/prey groups	Fishing pressure and/or productivity (but can be changed by both top down and bottom up processes)	Unclear	No	No	No	No	Likely low	Maybe	need to define prey
Diversity/ Richness										
-total diversity	Species pool and total abundance influences calculations	Diversity	Yes, and testable	No	Yes	Maybe	Maybe	Likely low	Yes	Species pool and total abundance influences calculation
-diversity within functional groups	Same as above, and need to define groups	Likehood of functional redundancy and functional diversity	Yes, but habitat may confound analysis	No	Yes	Maybe	Maybe	Likely low	Yes	Same as above; define functional groups
Age Distribution (abundance/ biomass)										
-all	Yes but requires VBGF data for entire assemblage	Fish assemblage productivity?	Yes, and testable (assumes constant VBGF)	Maybe	No	No	Maybe	Likely low	Maybe	Need VBGF for all species and spatial/temporal variance
-within target groups/ other subset	Yes but requires VBGF data for entire subset of species	Fisheries productivity?	Yes, and testable (assumes constant VBGF)	Yes (e.g. for fishery subset)	No	No	Maybe	Likely low	Maybe	Need VBGF for all species and spatial/temporal variance

Multivariate methods (e.g. MDS)	Likely need to use functional groups as response variables and aggreage to groups found everywhere	Community differences	Probably, but unknown	No	Maybe	Maybe	Maybe	Unknown	Yes	Need to reduce to groups that exist in all places (i.e. must aggregate to few functional groups)

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